Colour Blindness and the Trichromatic Theory of Colour-vision.

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Quite recently I have had the good fortune to examine in detail a case of red-blindness in a gentleman I will call X. The results of his observations with the spectrum I wish to place before the Royal Society, as they are confirmatory of the sensation curves of green and blue which I obtained with my own eyes. These curves are given in my paper read on May 18, 1905, to the Royal Society, and printed in the 'Philosophical Transactions' of that year.*

The examination of X lasted several half days, so that there was ample opportunity to repeat observations, an opportunity which is rarely afforded me by casual cases which from time to time I examine.

X is completely red-blind; he perceives no sensation of red whatever. In his youth he was accustomed to call grass red, but he explained it was due to his having learnt that the brilliancy of the green which represents the colour of grass to the normal eye was sometimes called red. He had no inclination whatever to call any colour yellow: green he called green, and the shades of yellow and red which contain a little green he called dark green. He matched a green (to normal colour-vision) in the spectrum with the white of the electric arc light. The standard scale number (S.S.N.) of his match was 34·6 (λ 5025), to which he invariably came back time after time.

On the less refrangible side of this "neutral" point he called all the spectrum colours green; some near the neutral point were to him pale, then below was pure green, and lower still, in the red, dark green. On the more refrangible side of the neutral point he called all colours blue; those near the neutral point were pale, those further on blue, and in the violet dark blue. He saw no violet as a separate colour. He matched it with dark blue. Parenthetically it may be remarked that this accords exactly with the results given in the paper alluded to, where it is shown that violet consists of blue and red sensations, and that the red in the violet is scarcely visible when the retina is fatigued with red.

The maximum luminosity to X in the prismatic spectrum is close to S.S.N. 46 (λ 5596), which agrees with the maximum of the green sensation

* "Modified Apparatus for the Measurement of Colour and its Application to the Determination of the Colour Sensations."

in the above-named paper. The luminosity of the spectrum was taken by X on two or three occasions, and the results are given in Table I, Column IX. It should be stated that the method of measuring the luminosities was that given by General Festing and myself in our paper on Colour Photometry.*

The actual readings of X's luminosities are, by chance, double of those given in the sensation curves of green and blue when added together (see Table I, Column VIII). In any case, the reduction of X's readings would have been made to bring them to the same maximum as that of the green sensation curve. The reason for this will be given later.

It will be noticed that all X's readings in the orange, yellow, and green are very closely the same as those given for the luminosity curves of the green and blue sensations when added together. In the blue and violet they are slightly larger; this, perhaps, is due to a difference in the absorption by the yellow spot. If the red component had been added to the blue sensation curve in this last region, the readings of X would be much below the compounded luminosity. *Primâ facie* this is additional evidence of the absence of the red sensation in the violet as seen by X.

In the next series of observations by X it will be seen that his luminosities of the different parts of the spectrum are confirmed.

These observations were the matching in luminosity and "hue" of a patch of white light by a mixture of two colours, one on each side of the "neutral" point. Two standard places in the spectrum were chosen, in each of which was placed a slit—one in the red, in which it was known that the blue sensation was absent though the green sensation was present, and the other in the violet in that position in which the green sensation was absent.

The relative luminosities of these two rays when passing through equal apertures of slits was determined by X: that in the red (S.S.N. 56·82) being 2, and that in the violet (S.S.N. 9·11) 0·14. These luminosities, though taken on a different day to those on which the luminosity curves were taken, agree well with the luminosities shown by the curve at these points.

The observations were made as follows:—The slits were first of all kept in the standard places and a series of matches made with the white by opening or closing the slits till the right hue was acquired. The luminosity of the white patch when it matched in luminosity the mixed colours (the two patches being in contact with one another, each being $\frac{3}{4}$ inch square) was measured by introducing, into the path of the beam forming it, sectors, the apertures of which opened and closed at pleasure during rotation. The aperture of the sector indicated the white luminosity. The relative widths of the slits were measured by placing a lens of very short focus in the path of

* Bakerian Lecture, 'Phil. Trans.,' 1886.

one of the slits. This gave a magnified image of the aperture on a distant screen on which a $\frac{1}{2}$-mm. scale was fastened. When the aperture of one slit was measured the slide in the spectrum carrying the slits was moved, so that the second slit was illuminated by the same colour. The slide was then moved back to the position it first occupied, the small lens moved away and fresh readings were taken. (Care was taken that the small lens always occupied the same place in relation to the first slit when it had to be replaced.) When a series of observations with the slits in the standard positions had been made, the red slit was moved to the sodium D light and a fresh series made with the first slit in that position and the second in the standard position in the violet. A series of readings was made as before. The "red" slit was then moved into various positions between S.S.N. 56·8 and the neutral point, the "violet" slit remaining fixed and matches made with the white. When this was finished the red slit was placed at D and matches of white made with the violet slit when in different parts of the spectrum on the more refrangible side of the spectrum. (The D light was chosen for the "red" slit, as it contained a larger amount of green sensation than the standard position, which was convenient.) Where the width of either or both of the slits was very small, the aperture to be measured was increased by placing in the path of one or both of the rays a small cardboard sector with fixed apertures. After measuring the apertures they were one or both diminished according to the aperture of the cardboard sector.

The method by which the composition of the different rays was determined is shown below, two examples illustrating it.

The "red" slit was placed at S.S.N. 48·8, the violet slit being at the standard place S.S.N. 9·11. The equation to match white was, in terms of slit apertures,

$$\text{(i)}\quad \overset{(48{\cdot}8)}{41} + \overset{(9{\cdot}11)}{106} = \overset{\text{White.}}{55.}$$

Increasing this equation to make 100 white, we have

$$\text{(ii)}\quad \overset{(48{\cdot}8)}{75} + \overset{(9{\cdot}11)}{193} = \overset{\text{White.}}{100.}$$

The standard equation with S.S.N.'s 56·82 and 9·11, in terms of slit apertures, had been found to be

$$\text{(iii)}\quad \overset{(56{\cdot}82)}{1116} + \overset{(9{\cdot}11)}{228} = 100.$$

Equating (ii) and (iii), we get

$$\overset{(48{\cdot}8)}{75} = \overset{(56{\cdot}82)}{1116} + \overset{(9{\cdot}11)}{35.}$$

Multiplying the right-hand members by 2 and 0·14 respectively, we get, after dividing by 75, the luminosity of S.S.N. 48·8 as

$$\overset{\text{G.S.}}{29{\cdot}9} + \overset{\text{B.S.}}{0{\cdot}065},$$

in luminosities (G.S. and B.S. being used as the symbols of green and blue sensations).

Again, for S.S.N. 46·23 we have the following equation :—

$$\overset{(46{\cdot}23)}{18} + \overset{(9{\cdot}11)}{46} = \overset{\text{W.}}{25},$$

or

$$\overset{(46{\cdot}23)}{72} + \overset{(9{\cdot}11)}{184} = \overset{\text{W.}}{100}.$$

Equating this with (iii) and converting the slit apertures into luminosities, we get

$$\text{Luminosity of S.S.N. } 46{\cdot}23 = \overset{\text{G.S.}}{31{\cdot}5} + \overset{\text{B.S.}}{0{\cdot}085}.$$

In this manner the luminosities of the different wave-lengths to X were worked out.

The following is a table of the final determinations :—

S.S.N.	G.S.	B.S.	S.S.N.	G.S.	B.S.
54·27 =	7·5 +	0·003	35·62 =	11·2 +	0·093
50·6 =	22·0 +	0·005	30·22 =	4·05 +	0·155
48·8 =	29·9 +	0·065	25·01 =	0·77 +	0·238
46·23 =	31·5 +	0·085	19·71 =	0·11 +	0·252
40·92 =	26·5 +	0·086	14·39 =	0 +	0·203
38·62 =	19·2 +	0·068	9·11 =	0 +	0·140

These figures were plotted and a curve drawn through the points. The following table was then constructed from the curves.

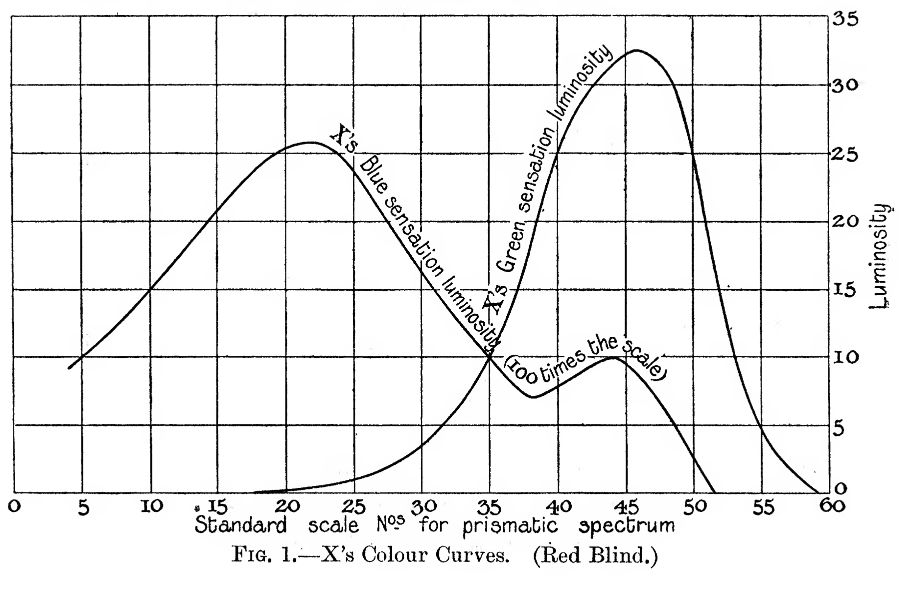

Fig. 1.—X's Colour Curves. (Red Blind.)

Column I is the Standard Scale No. (S.S.N.), Column II is λ, Columns III and IV the green and blue sensation curves derived from X's equations, Column V his luminosity curve by the addition of III and IV, Columns VI and VII are the curves of the green and blue sensations taken from the paper in the 'Phil. Trans.,' Column VIII is the luminosity derived from the addition of VI and VII, Column IX is X's luminosity curve taken direct and reduced as before described.

Table I.—Table showing X's Sensation Curves as Luminosities, also the same Curves from 'Phil. Trans.,' also X's Total Luminosity Curve taken direct.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
S.S.N.	λ.	X's sensation curves in luminosities.		X, G.S. + B.S. added.	Colour sensation in luminosities from 'Phil. Trans.'		Normal, G.S. + B.S. added.	X's luminosity curve taken direct.
		G.S.	B.S.		G.S.	B.S.		
58	6521	1 ·0	—	1 ·0	0 ·21	—	0 ·21	0 ·2
56	6330	2 ·5	—	2 ·5	2 ·25	—	2 ·25	2 ·25
54	6152	7 ·2	trace	7 ·2	7 ·60	—	7 ·60	7 ·5
52	5996	15	"	15 ·0	15 ·36	—	15 ·36	15 ·1
50	5850	25	0 ·024	25 ·02	25 ·00	—	25 ·00	25 ·0
48	5720	31	0 ·062	31 ·06	31 ·78	0 ·029	31 ·81	32 ·0
46	5596	32 ·5	0 ·087	32 ·59	32 ·70	0 ·090	32 ·79	32 ·5
44	5481	31 ·5	0 ·100	31 ·6	31 ·30	0 ·118	31 ·42	31 ·5
42	5373	29 ·2	0 ·093	29 ·3	27 ·75	0 ·122	27 ·87	27 ·5
40	5270	25	0 ·080	25 ·8	24 ·09	0 ·112	24 ·20	24 ·0
38	5172	18 ·5	0 ·07	18 ·57	18 ·43	0 ·091	18 ·52	18 ·5
36	5085	12	0 ·090	12 ·09	12 ·83	0 ·101	12 ·90	13 ·0
34	5002	8 ·3	0 ·110	8 ·41	7 ·86	0 ·124	7 ·98	7 ·5
32	4924	5 ·5	0 ·134	5 ·63	4 ·77	0 ·145	4 ·92	4 ·5
30	4848	3 ·5	0 ·160	3 ·66	3 ·08	0 ·174	3 ·83	3 ·0
28	4776	2 ·2	0 ·190	2 ·39	2 ·03	0 ·202	2 ·23	2 ·0
26	4707	1 ·2	0 ·220	1 ·42	1 ·15	0 ·243	1 ·39	1 ·2
24	4639	0 ·5	0 ·25	0 ·75	0 ·53	0 ·262	0 ·79	0 ·95
22	4578	0 ·3	0 ·255	0 ·55	0 ·27	0 ·247	0 ·52	0 ·75
20	4517	0 ·11	0 ·253	0 ·36	0 ·10	0 ·234	0 ·33	0 ·55
18	4459	0 ·04	0 ·242	0 ·28	0 ·04	0 ·202	0 ·24	0 ·42
16	4404	—	0 ·224	0 ·22	0 ·01	0 ·180	0 ·19	0 ·25
14	4349	—	0 ·195	0 ·19	—	0 ·154	0 ·15	0 ·22
12	4296	—	0 ·175	0 ·17	—	0 ·126	0 ·13	0 ·20
10	4245	—	0 ·150	0 ·15	—	0 ·098	0 ·10	0 ·17
8	4198	—	0 ·13	0 ·13	—	0 ·073	0 ·07	0 ·125

A different set of observations was also made by X. He was asked to match the various colours of one spectrum by a mixture in a second spectrum of D light (S.S.N. 50·6) and one ray in the violet. These

observations were excellently carried out, but as the matching really meant adding white (X's) to one of his two colours, his accuracy was not quite equal to that he obtained in his white matching. The results, however, were used as a check on the previous observations.

The results obtained from the measures made by X are valuable for a special reason besides those which are apparent in the foregoing pages. It has frequently been asserted that when luminosities are taken in the way that I have adopted, something is measured which is not luminosity. There are various answers to this assertion which it is scarcely necessary to summarise here. But X, when he made his colour equations, matched the white with the rays coming through different apertures of slits, and the only luminosity he measured was the luminosity of the two white patches, to which no objection can be raised. It was only when these readings had been made that the question of luminosity entered into the problem. Only two luminosities of coloured rays were measured and these were applied to his slit apertures to find the luminosity of the different rays. As mentioned before, the luminosity measured direct and that derived from the equations are practically identical, so that a totally different kind of measurement confirms the direct method of measuring the luminosity.

I now give the reason for adopting as the maxima of the luminosity curves of the red-blind and the green-blind the figures 32·8 and 80·6 respectively when that of normal colour-vision is taken as 100.

There may be sometimes a variation in the sensitiveness to *light* of persons who have normal vision, but in the large majority of cases the reduction in luminosity required just to extinguish light is the same, always supposing that their eyes are not myopic or astigmatic. (If myopic or astigmatic, the small disc of light which is seen just before extinction will appear before it does with normal form vision, and the light will be extinguished earlier.) If the colouring matter in yellow spot varies (as it often does), then the extinction of a blue ray would vary accordingly. Let us suppose that the form vision of a red-blind, a green-blind, and a person having normal colour-vision to be normal; then when different rays of the spectrum are extinguished by proper means, if the amount of reduction of intensity to extinguish the violet of the spectrum is the same for all when the initial white light is the same for all (taking into account that the red-blind feels no red sensation in the violet region), we may take it that the sensitiveness to light is the same as given by adding together those colour sensation curves that are applicable to the three kinds of colour-vision as given in the 'Phil. Trans.,' which implies that the maxima must be those stated. A concrete example will make my meaning clear. A green-

blind and red-blind were tested for the luminosity and also for the extinction of the different rays of the spectrum. Their luminosity and extinction are given in the next table (Table II). The extinction was made when the patch of light made by the D ray (which has the maximum luminosity to normal

Table II.—Extinction of different Colours of the Spectrum by a Green-blind and Red-blind.

S.S.N.	λ.	Green-blind.			Red-blind.		
		Extinction when D = 1 candle at 1 foot in millionths of original luminosity to normal vision.	Luminosity.	Extinction when every ray is 1 candle to green-blind.	Extinction when D = 1 candle at 1 foot in millionths of original luminosity to normal vision.	Luminosity.	Extinction, when every ray is 1 candle to red-blind.
60	6728	1200	7·2	—	—	—	—
58	6521	550	22·2	122	—	—	—
56	6330	260	46·0	119·6	770	2·5	192
54	6152	150	72·2	75·8	250	7·6	190
52	5996	65	80·6	52·3	90	16·6	149
50	5850	25	74·4	18·6	27	27·1	72·7
48	5720	12·5	66·1	8·26	15	31·4	47·1
46	5596	7·5	55·5	4·16	10	32·8	32·8
44	5481	5·5	45·5	2·50	7	30·5	21·35
42	5373	5	35·5	1·77	5·5	27·0	14·8
40	5270	5	26·5	1·32	5	21·4	10·7
38	5172	5	18·0	0·90	5	15·2	7·6
36	5085	6	11·9	0·71	6	9·5	5·7
34	5002	7	7·23	0·50	7	6·0	4·2
32	4924	9	5·05	0·45	9	3·8	3·42
30	4848	12·5	3·61	0·45	11	3·0	3·30
28	4776	17	2·79	0·476	14·5	2·3	3·48
26	4707	25	2·07	0·52	17·5	1·9	3·32
24	4630	34	1·55	0·53	22·0	1·5	3·30
22	4578	45	1·24	0·56	30·0	1·12	3·36
20	4517	75	1·03	0·77	42	0·87	3·65
18	4459	125	0·72	0·90	60	0·61	3·66
16	4404	205	0·62	1·27	87	0·44	3·82
14	4349	225	0·52	1·17	115	0·33	3·79
12	4296	270	0·43	1·16	130	0·28	3·64
10	4245	320	0·34	1·09	160	0·23	3·68

colour-vision) was to normal vision one candle at 1 foot distance from the screen. The extinctions are given in 1/1,000,000 of the original luminosity of the rays to each observer respectively; a second column shows the luminosity of the colour-blind when the maxima are made 80·6 and 32·8

respectively. Another column is added, which is made by multiplying the extinction by the luminosity, which gives the result of the extinction that would occur if every ray were made of a luminosity of one candle. The numbers are shown graphically in fig. 2. From this method of treating the extinctions it is no matter if the absorption by the yellow spot is greater in one case than another, since all rays are reduced to the luminosity of one candle at 1 foot distance from the screen.

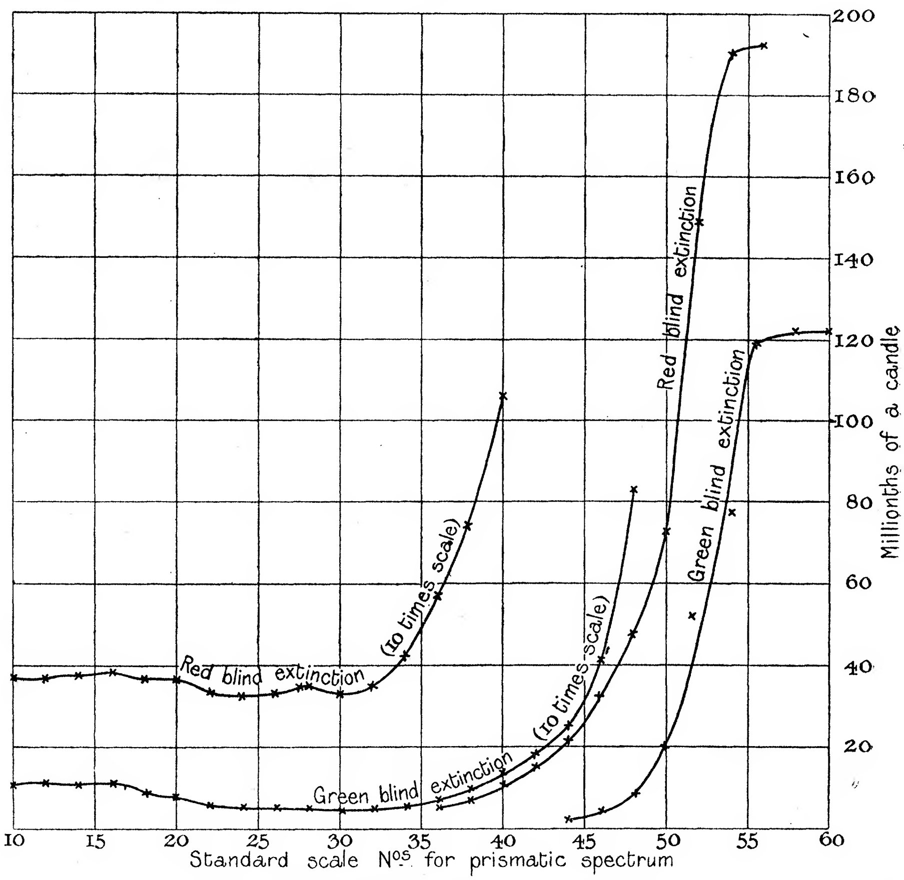

FIG. 2.—Red and Green Blind Extinction Curves, each Ray having originally to them the Luminosity of one Candle.

In the violet, in which there is no green sensation, from S.S.N.'s 10 to 16 the average extinction for the green-blind is just 1·17, whilst it is 3·74 for the red-blind. The ratio of the first to the second is thus 31 to 100. This should be the ratio of the blue sensation (B.S.) alone to the blue and red sensations (B.S. + R.S.) when both exist. In the table giving the curves and percentages of sensations in the violet the ratio taken is 28 to 100. (The

reason for adopting a ratio is evident if it is remembered that the red sensation is extinguished long before the blue.) In 'Photometry,' Part III, by the author and General Festing, 'Phil. Trans.,' A, 1892, the average extinction of S.S.N.'s 10 to 16 is 1·21, which within limits of error of observation is the same as the green-blind, viz. 1·17. This was to be expected. It appears, then, we are justified in assuming that the total light to which the green- and red-blind and normal colour-vision are sensitive are as the areas of the curves of luminosity with the maxima of 80·6, 32·8, and 100—which are 582, 253, and 830.

In the trichromatic theory of colour-vision, the three sensations of red, green, and blue are each totally distinct, and in complete green- or red-blindness one of these two sensations, green and red, is totally absent. It therefore follows, if this theory is not merely a working hypothesis, the luminosity curve of the red blind, if added to that of the green-blind, when the above numbers are taken as maxima, should give the luminosity curve of normal colour-vision, with one luminosity curve of the blue sensation in addition. For red-blind luminosity is composed of green sensation + blue sensation, the green-blind curve of red sensation + blue sensation, and the normal colour-vision curve of all three sensations. By the addition of the red- and green-blind luminosity curves we have that of normal colour-vision curve, together with an extra blue sensation. The luminosity of the blue sensation is very small compared with the other two, and may vary slightly, as said before, owing to difference in the absorption by the yellow spot, so that roughly the addition of the red-blind and green-blind curves should be very close to the curve of normal vision. We will, however, take, in the first place, D's luminosity curve and X's green luminosity curve only, which should give, when added together, the normal colour-vision curve closely, as only one blue sensation curve will be found in the compounded curve. Table III gives the results. The comparison of the compounded curve with that taken direct by the normal colour-vision eye shows how closely they are alike, and the similarity is very remarkable considering that curves of three different persons have to be used.

In the table, Column I is the S.S.N., Column II the wave-length, Column III shows D's luminosity curve, Column IV is the green sensation of X in luminosity, Column V gives the results of the addition of D's luminosity to X's, whilst Column VI shows the luminosity curve for normal colour-vision. Columns V and VI have to be compared together to test the strength of the theory.

As a further test, the next table (Table IV) contains the luminosity curves of three green-blind (including D's) and of four red-blind. The mean curve

Table III (February 13, 1910).

I.	II.	III.	IV.	V.	VI.
S.S.N.	λ.	D's luminosity.	X, green sensation luminosity.	III and IV added.	Normal luminosity.
62	6957	2	—	2	2
60	6728	7·2	—	7·2	7
58	6521	22·2	1·0	23·2	21
56	6330	46	2·5	48·5	50
54	6152	72·2	7·2	79·4	80
52	5996	80·6	15·0	96·1	96
50	5850	74·4	25·0	99·4	100
48	5720	66·1	31	97·1	97
46	5596	55·5	32·5	88·0	87
44	5481	45·5	31·5	77·0	75
42	5373	35·5	29·2	64·7	62·5
40	5270	26·5	25	51·5	50
38	5172	18·0	18·5	36·5	36
36	5085	11·9	12	23·9	24
34	5002	7·2	8·3	15·5	14·2
32	4924	5·0	5·5	10·5	8·5
30	4848	3·6	3·5	7·1	5·7
28	4776	2·8	2·2	5·0	4·0
26	4707	2·1	1·2	3·3	2·8
24	4630	1·5	0·5	2·0	1·9
22	4578	1·2	0·3	1·5	1·4
20	4517	1·03	0·11	1·14	1·1
18	4459	0·72	0·04	0·76	0·86
16	4404	0·62	—	0·62	0·70
14	4349	0·52	—	0·52	0·56
12	4296	0·43	—	0·43	0·45
10	4245	0·34	—	0·34	0·34

of each kind of colour-blindness is taken and added together. In the last column the normal luminosity curve, with one extra blue sensation, is shown.

According to the Hering theory, both D's and X's colour blindness is red-green blindness, the only difference between them being that the latter has a shortened spectrum. I am unaware how the shortened spectrum can be legitimately accounted for on this theory, but it is perfectly easy to understand on the Young-Helmholtz trichromatic theory, and the evidence adduced above would be difficult to get over.

It may be remarked that it is only when an hypothesis of colour-vision is submitted to quantitative measurement that its correctness or otherwise can be endorsed or refuted. If the facts above given do not fall in with what I may call the physiological hypothesis of colour-vision, that hypothesis

Table IV.—Luminosities of Three Green-blind and Four Red-blind. The Mean Luminosities of the Red- and Green-blind are added together and compared with the Luminosity of the Normal Colour-vision, to which an extra Blue Sensation Luminosity is added.

S.S.N.	λ.	Green-blind.				Red-blind.					Addition of IV and IX.	Luminosity of normal colour-vision + B.S.
		I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
		E.	F.	D.	Mean.	G.	H.	K.	L.	Mean.		
62	6957	2	2	2	2	—	—	—	—	—	2	2
60	6728	7	7·6	7·2	7·3	—	—	—	—	—	7·3	7
58	6521	20	21·8	22·2	21·3	—	—	—	—	—	21·3	21
56	6330	46	48	46	46·7	3·3	3·0	2·8	3	3·0	49·7	50
54	6152	75	71	72·2	72·7	8·1	7·5	7·1	7	7·4	80·1	80
52	5996	80	81·6	80·6	80·5	16·6	16·5	13·7	17	15·9	96·4	96
50	5850	75	77	74·4	75·5	27	24	26·2	25	25·5	101·0	100
48	5720	67	64·8	66·1	66·0	31·4	30	32·0	30	30·8	96·8	97
46	5596	56	55·8	55·5	55·7	32·8	32·5	33	33	32·8	88·5	87
44	5481	45	46·0	45·5	45·5	30·5	32	31·2	32	31·7	77·2	75·1
42	5373	35·5	35	35·5	35·3	27	28	28·3	28	27·8	63·1	62·7
40	5270	27·1	26·4	26·5	26·7	21·4	24·5	23·3	23	23	49·7	50·1
38	5172	16·5	18·0	18·0	17·5	15·2	17	18·1	17	16·8	34·3	36·1
36	5085	10	11·0	11·9	10·9	9·5	11·5	12·5	10	10·9	21·8	24·5
34	5002	6·2	6·2	7·2	6·5	6·0	6·5	6·8	6·8	6·5	13·0	14·3
32	4924	4·5	3·4	5·0	4·3	3·8	4·0	4·4	4·4	3·9	8·2	8·6
30	4848	3·4	2·5	3·6	3·2	2·4	2·8	2·5	3·2	2·7	5·9	5·9
28	4776	3·0	2·0	2·8	2·6	2·2	2·0	2·0	2·6	2·2	4·8	4·2
26	4707	2·5	1·65	2·1	2·1	1·9	1·0	1·2	1·9	1·5	3·5	3·0
24	4630	2·0	1·30	1·5	1·6	1·4	0·7	0·8	1·0	1·0	2·6	2·2
22	4578	1·7	1·00	1·2	1·3	1·1	0·5	0·5	0·7	0·7	2·0	1·65
20	4517	1·5	0·75	1·0	1·0	0·8	0·3	0·3	0·3	0·4	1·5	1·33

requires further consideration. There are many assertions made on behalf of this latter theory which require experimental proof. For instance, it has been stated recently in print that the yellow of the spectrum does not cause "fatigue" for the red and green. If this be a fact it would be, in all probability, a separate sensation which, according to the Hering theory, it is. According to experiments, made with my own eyes and others, the yellow does fatigue both the green and the red perceiving apparatus (wherever such "apparatus" may be situated). If the yellow is compounded of red and green sensations, as it is in the trichromatic theory, the fatigue of the red apparatus or of the green apparatus should alter the hue of the yellow. If

we place a patch of red light in close proximity to a patch of yellow, and cover up the yellow and close one eye, and steadily look at the red patch with the other, and then cover up quickly the red and uncover the yellow, it will be found that the yellow appears much greener than it originally appeared, and the unfatigued eye will confirm that observation. Indeed, a third patch of yellow may be placed alongside the original yellow patch to make a match with the altered colour by the use of the two eyes. Again, the eye may be fatigued with the green and the yellow will be redder than it appeared before it was fatigued. There will be found no appreciable difference from the original colour with the unfatigued eye, but without such confirmation the memory of what the yellow was originally will enable the experimenter to assure himself of the change in hue. These experiments go to show that, at all events when the eye is submitted only to ordinary illumination, there is no sympathetic action caused in the other.

The red and green also show that fatigue by the yellow gives red and green fatigue by similar kinds of observations.

These experiments go to show that the yellow is made up of red and green sensations. There is a yellow at S.S.N. 48·8, which shows the change of colour with fatigue by red or by green very markedly; at this point the red and green sensation curves "of equal stimulation" cut, and the shift in the colour after fatigue is very strongly shown.

I have cases of incomplete red- and green-blindness which again go to confirm the Young-Helmholtz trichromatic theory, but I reserve these for the present.